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Treatment of Groundwater Arsenic using Botanical Tools

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ABSTRACT

Arsenic (As) is the one the most toxic element present in earth which poses a serious threat to the environment and human health. Arsenic contamination of drinking water in South and Southeast Asia reported one of the most threatening problems that causes serious health hazard of millions of people of India and Bangladesh. Further, use of arsenic contaminated ground water for irrigation purpose causes entry of arsenic in food crops, especially in Rice and other vegetable crops. Currently various chemical technologies utilized for As removal from contaminated water like adsorption and co-precipitation using salts, activated charcoal, ion exchange, membrane filtration etc. are very costly and cannot be used for large scale for drinking and agriculture use. In contrast, phytoremediation utilizes green plats to remove pollutants from contaminated water using various mechanisms such as rhizofiltration, phytoextraction, phytostabilization, phytodegrartion and phytovolatilization. A large numbers of terrestrial and aquatic weed flora have been identified so far having hyper metal, metalloid and organic pollutant removal capacity. Among the terrestrial weed flora *Arundo donax, Typha latifolia, Typha angustifolia, Vetivaria zizinoids* etc. are the hyper As accumulator. Similarly *Eicchornea crassipes* (Water hyacinth), *Pistia stratiotes* (water lettuce), *Lemna minor* (duck weed), *Hyrdilla verticillata, Ceratophyllum demersum, Spirodella polyrhiza, Azola, Wolfia* spp., etc. are also capable to extract higher amount of arsenic from contaminated water. These weed flora having As tolerance mechanism in their system and thus remediate As contaminated water vis-à-vis continue their life cycle.

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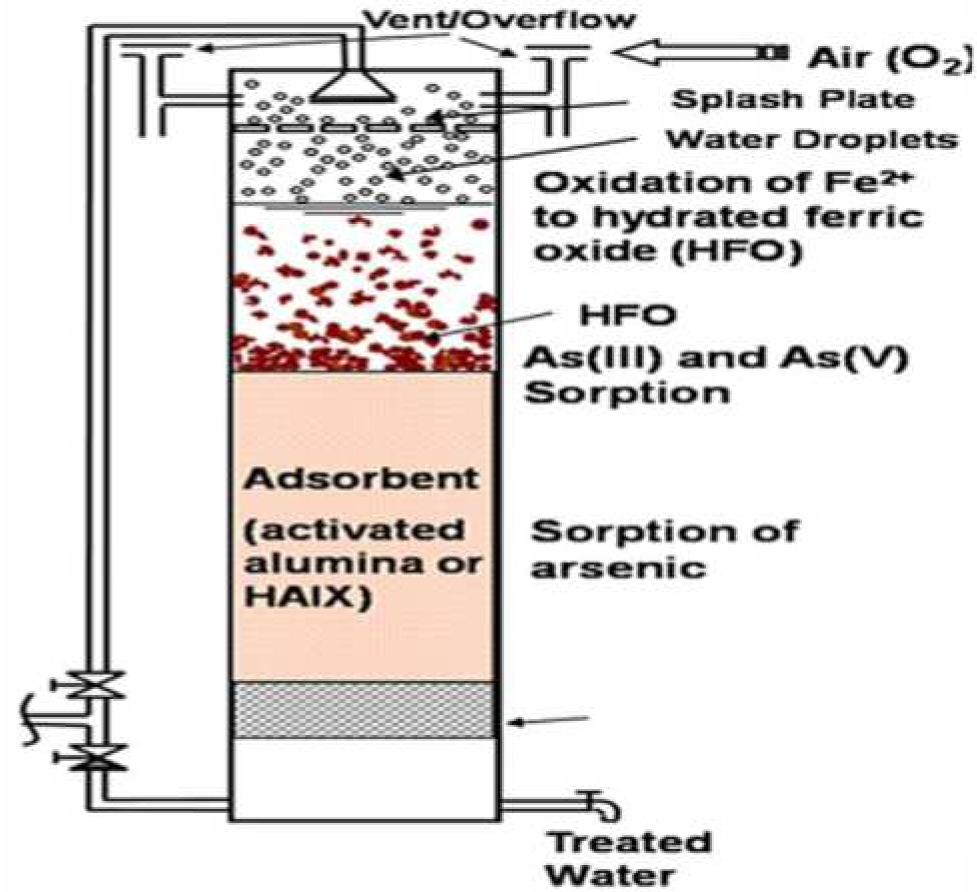
INTRODUCTION

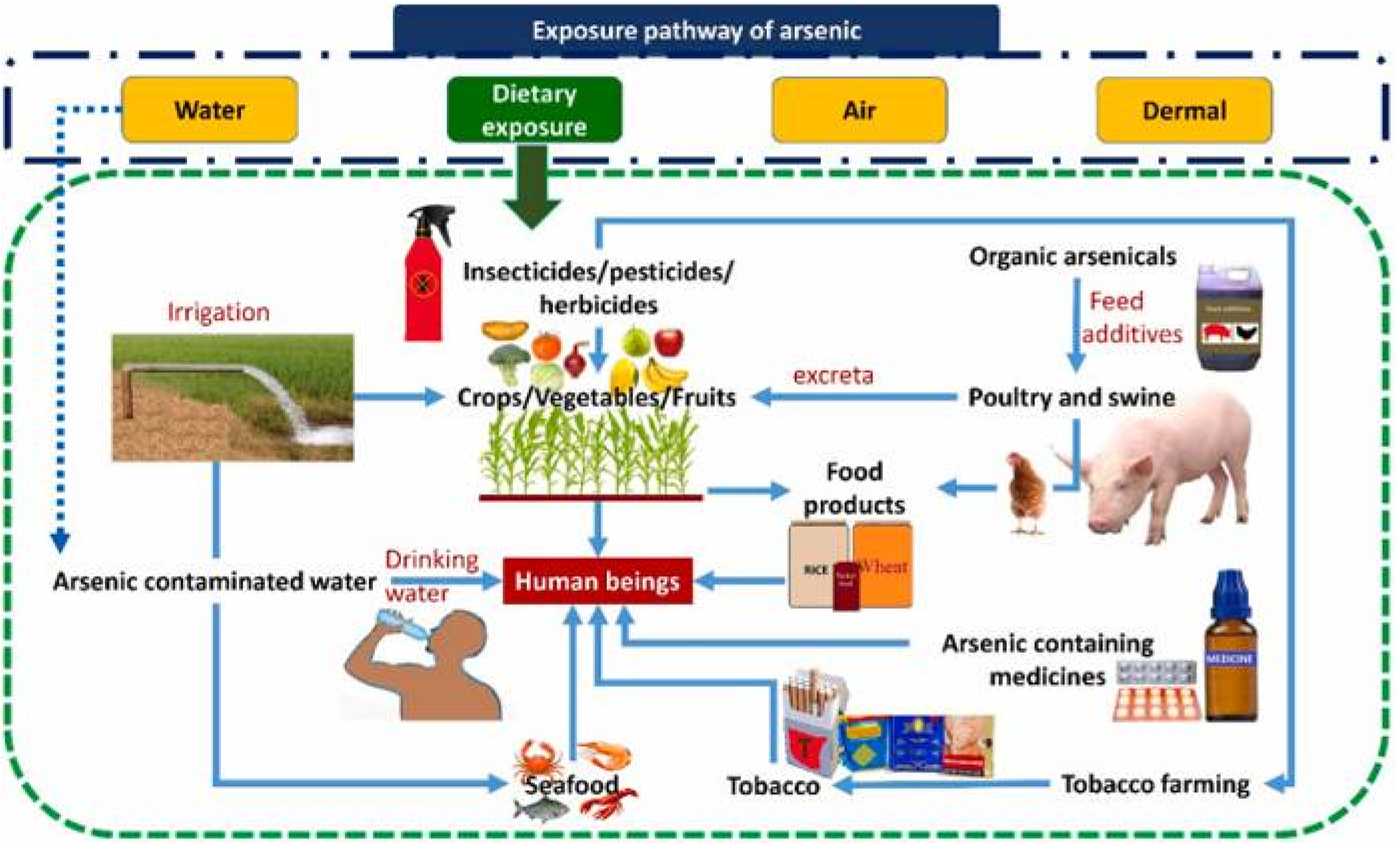
Arsenic (As) toxicity in soil and water is an increasing menace around the globe. Its concentration both in soil and environment is due to natural and anthropogenic activities. Rising arsenic concentrations in groundwater is alarming due to the health risks to plants, animals, and human beings. Anthropogenic As contamination of soil may result from mining, milling, and smelting of copper, lead, zinc sulfide ores, hide tanning waste, dyes, chemical weapons, electroplating, gas exhaust, application of municipal sludge on land, combustion of fossil fuels, As additives to livestock feed, coal fly ash, and use of arsenical pesticides in agricultural sector. Phytoremediation can be viewed as biological, solar-driven, pump-and-treat system with an extensive, self-extending uptake network (the root system) that enhances the natural ecosystems for subsequent productive use. The present review presents recent scientific developments regarding phytoremediation of arsenic contaminated environments and its possible detoxification mechanisms in plants.[1,2]

Dealing with risk based corrective action and phytoremediation is inherently complex.



Arsenic groundwater treatment

The risk based corrective action or risk assessment, is used to evaluate the acceptable limits for contact with both an individual contaminant and combined risk of multiple contaminants. Environmental management decisions are usually made with limited information and must be projected over large time frames. There are many factors involved in the risk assessment and remediation of a site and not all may be known in the beginning. Environmental managers have to review the available knowledge from both a scientific and managerial viewpoint to make informed decisions and implement the most appropriate assessment and remedial options to mitigate the environmental contamination at a subject site. Water supply systems are the major source of human exposure to arsenic.[3,4] Arsenic is generally in the inorganic form in most water systems, occurring predominantly as As(V) in surface waters and as As(III) in groundwater containing high levels of total arsenic. Arsenic may be encountered in water from wells drilled in into arsenic-rich ground strata or where geochemical conditions favor arsenic dissolution and release into rivers, lakes and other bodies of water. It may also be found in water contaminated by industrial or agrochemical wastes. The US Geological Survey (USGS) has identified ground water with naturally high levels of arsenic throughout the United States. Certain foodstuffs are known to contain considerably more arsenic than most other foods. Unusually high concentrations of arsenic are found in many types of seafood. Marine crabs, lobster, shrimp, and cod typically contain arsenic levels of 10-40 ppm, and there have been instances where mussels contained as much as 120 ppm of arsenic. Marine organisms can contain arsenic at much higher levels than terrestrial organisms, there are no documented cases of arsenic poisoning by ingestion of marine organisms in the literature. This is explained by the fact that the major arsenical in most marine organisms is arsenobetaine, a water- soluble, trimethylated organoarsenical that poses little risk to the organism or its consumer. [5,6]

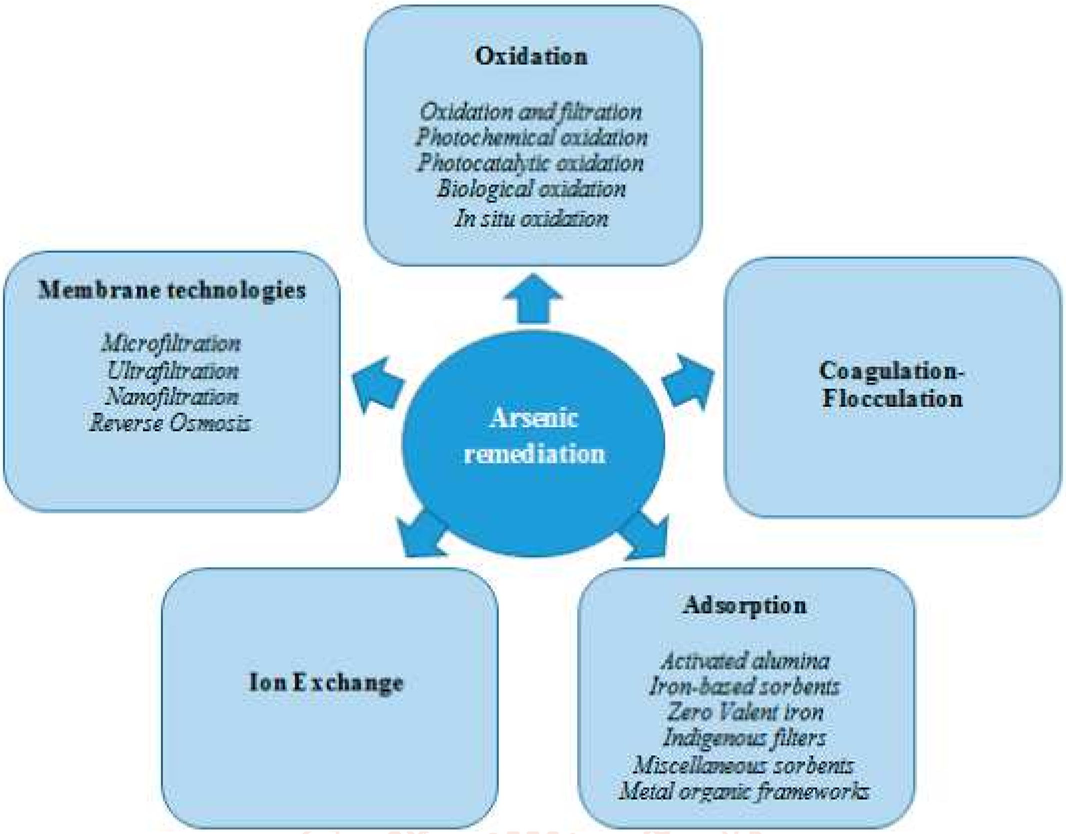


The environmental protection agency defines risk as the chance of harmful effects to human health or to ecological systems resulting from exposure to an environmental stressor. All chemical substances can produce adverse health effects at some level of exposure. The dose makes the poison. Risk is the likelihood that an adverse health effect will result from an exposure to a dose of chemical. Risk is a function of both toxicity and exposure, and without exposure there is not risk.[7,8] Risk assessment is a process designed to answer questions about how toxic a chemical is, what the probability that use will cause harm is, and how to characterize that risk. Environmental risk assessment is a scientific process that identifies and evaluates threats to the environment, in particular to living organisms, their habitats and ecosystems. The risk assessment process, includes various steps that meant to identify and evaluate risks, risk impacts, and evaluate risk mitigation measures. Risk management is the decision making process that entails consideration of the site information along with risk related information to develop, analyze, and compare options and to select the appropriate response to a potential health hazard. Using experience and judgment, the (risk) manager must determine a level of risk that is acceptable. The scope of risk assessment varies widely.[9,10]

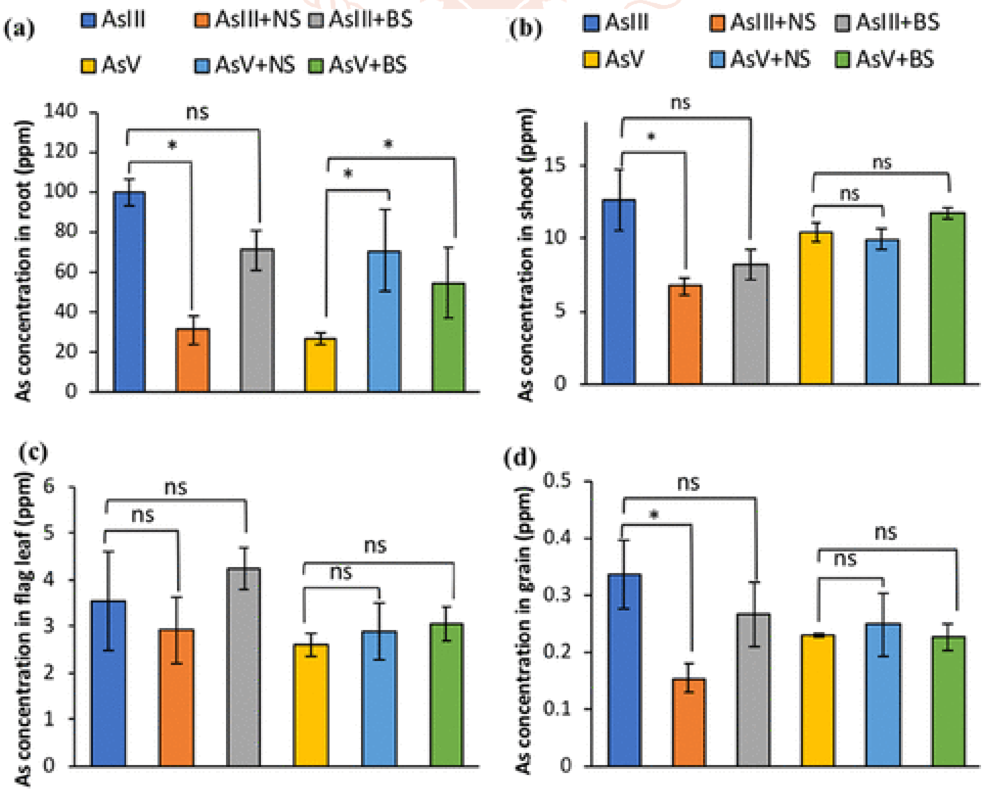
Phytoremediation consists of a collection of four different plant-based technologies, each having a different mechanism of action for the remediation of metal-polluted soil, sediment, or water. These include: rhizofiltration, which involves the use of plants to clean various aquatic environments;• phytostabilization, where plants are used to stabilize rather than clean contaminated• soil; phytovolatilization, which involves the use of plants to extract certain metals from soil• and then release them into the atmosphere through volatilization; and phytoextraction, where plants absorb metals from soil and translocate them to the• harvestable shoots where they accumulate.[11,12]

Discussion

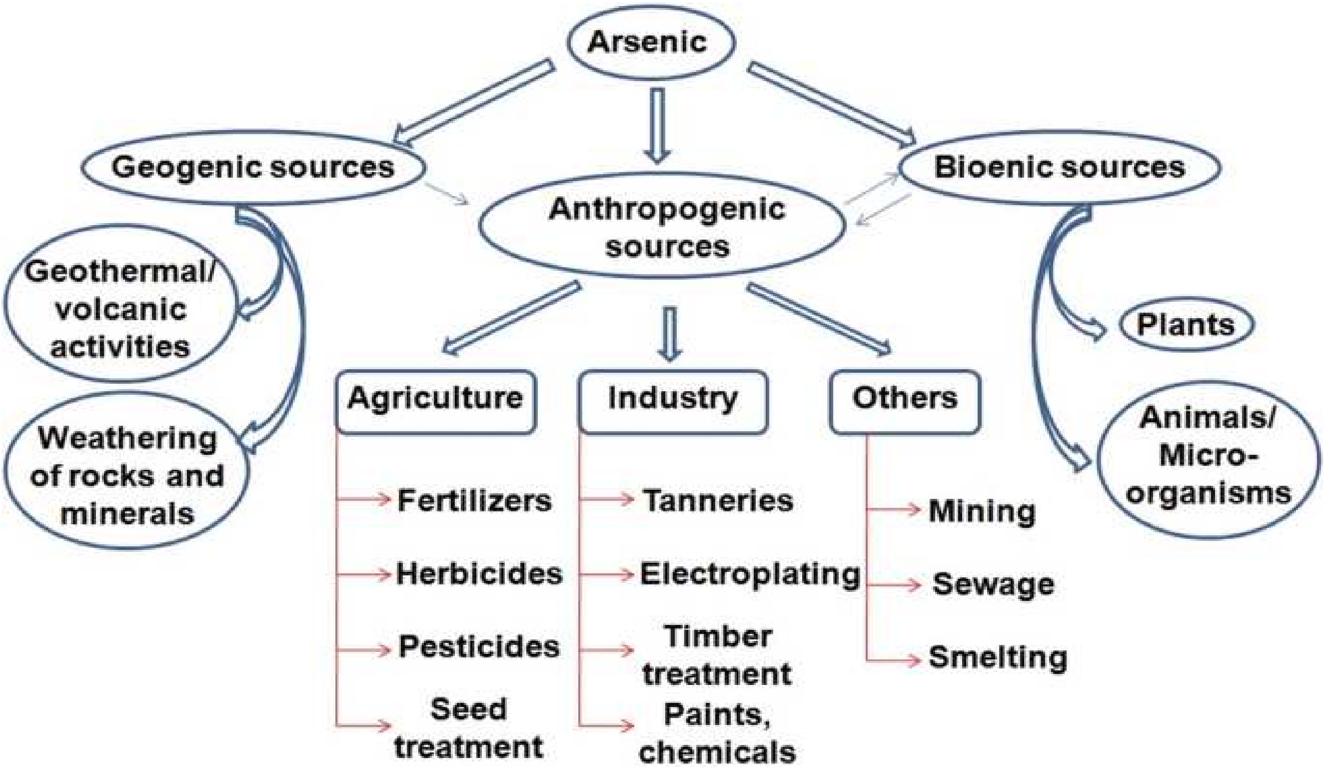
Phytoextraction is the most commonly recognized of all phytoremediation technologies, and is the focus of the present research work.



The terms phytoremediation and phytoextraction are sometimes incorrectly used as synonyms, but phytoremediation is a concept while phytoextraction is a specific cleanup technology. The phytoextraction process involves the use of plants to facilitate the removal of metal contaminants from a soil matrix . In practice, metal accumulating plants are seeded or transplanted into metal-polluted soil and are cultivated using established agricultural practices. The roots of established plants absorb metal elements from the soil and translocate them to the above-ground shoots where they accumulate.[13,14] If metal availability in the soil is not adequate for sufficient plant uptake, chelates or acidifying agents may be used to liberate them into the soil solution. After sufficient plant growth and metal accumulation, the above-ground portions of the plant are harvested and removed, resulting the permanent removal of metals from the site. The remaining root structure can either allowed to continue growth or new plants can be installed. A major factor influencing the efficiency of phytoextraction is the ability of plants to absorb large quantities of metal in a short period of time.

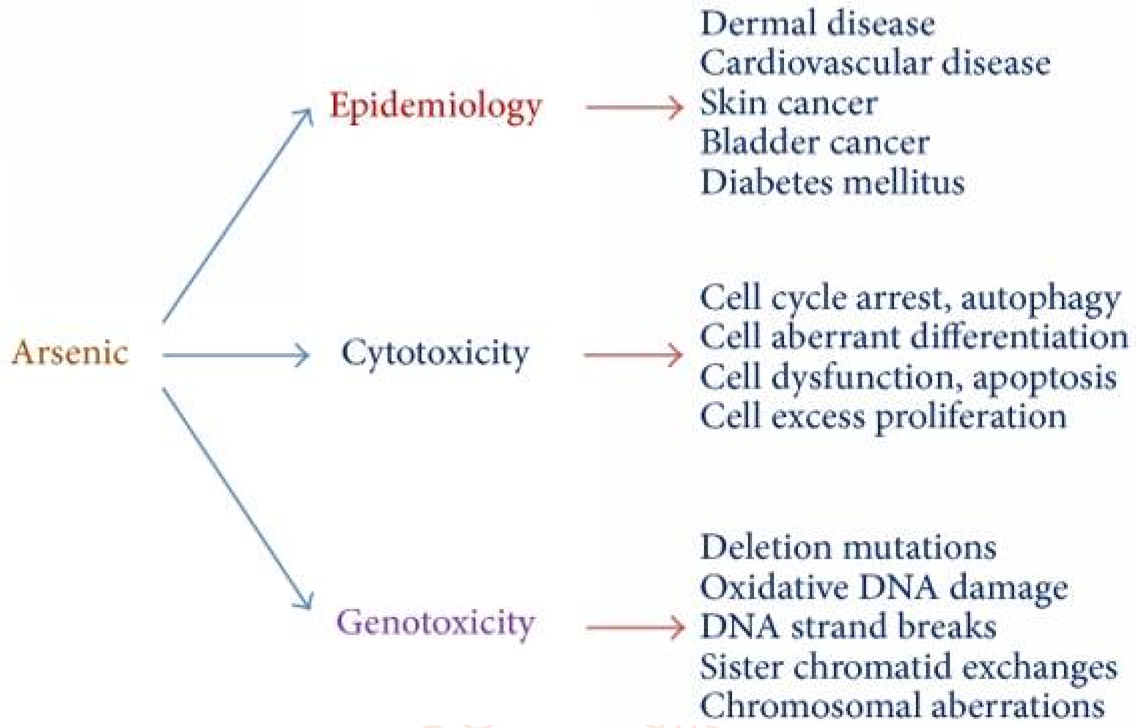


Although the total soil metal content may be high, it is the fraction that is readily available in the soil solution that determines the efficiency of metal absorption by plant roots. Soil pH is a major factor influencing the availability of elements in the soil for plant uptake. Poplar trees are commonly used for groundwater remediation because they are fast growing and can survive in a broad range of climates. They can also draw large amounts of water through soil and directly from aquifers through deep rooted planting techniques. As such, the poplar has the capacity to draw a greater amount of dissolved contaminant and reduce the risk of off-site exposure. Phytoremediation has a cost advantage over other treatment technologies because it relies on the use of the natural growth processes of plants with minimal operational and maintenance costs. Poplar root distribution can increase the transfer of oxygen throughout the root zone. This increases the equilibrium balance of arsenic, favoring arsenate and uptake through the plant system. [15,16] Poplars can be adapted to various climates and coupled with deep rooting techniques, can be used to draw water from deep underground. The removal of groundwater can create a hydraulic depression that stops the transport of contaminants. As in a natural pump and treat system, the tree root system of a poplars will transpire water and draw down the water table in the areas below the tree. However, a disadvantage of phytoremediation is that the roots must be able to reach the contaminated groundwater for remediation, therefore, making phytoremediation an unfeasible remedial technology for deep contaminated aquifers. Some companies such as Tree mediation have patented systems to treat deep contaminated soil and groundwater.



Nepal is located in the vicinity of Himalayas. Nearly 47% (11 million) of the total Nepalese population lives on the flat lands located in the southern part of the country, the Terai region. The majority (90%) of people living in the Terai region of Nepal depends on groundwater as their primary source of potable water. Out of 24 674 tested wells in the Nawalparasi district approximately 7896 wells (32%) had As concentrations greater than 10 $\mu g \cdot L^{-1}$ (safe-water limit set by WHO). In addition, 3676 wells (14.9%) had As concentrations greater than 50 $\mu g \cdot L^{-1}$ (standard permissible limit proposed by Nepal). However, at present, none of the wells in the Terai districts of Nepal are free from As. Based on sediment-aquifer studies, the Siwalik Hills and the higher Himalayas are assumed to be the possible sources of As in the Terai region. Leaching of As from natural rocks has been the main source of groundwater contamination in Nepal. However, little is known about the mechanism of As release in the Terai groundwater. High levels of As contamination in the drinking water poses a serious risk to the health of resident living in the Terai plain regions. In the region, 23% (2.53 million, based on WHO guideline of 10 $\mu g \cdot L^{-1}$) and 5% (0.5 million, Nepal's standard of >50 $\mu g \cdot L^{-1}$) of population are at the risk of As exposure. Chronic exposure to As imparts characteristic skin manifestations (pigment change), melanosis and keratosis. The prevalence of arsenicosis was found to be 3.6%, 0.9%, and 0.7% in Nawalparasi, Rupandehi, and Kapilavastu districts, respectively. Arsenicosis is most prevalent among the male population, especially those in their late 50s. The most promising approach for the removal of As to acceptable levels include the use of Gagri filters and iron-assisted bio-sand filters. [17,18]

Effect of arsenic pollution in human health



Skin and systemic manifestations

The specific skin diseases are pigmentation and keratosis, which are caused by chronic arsenic toxicity. The first population-based survey in West Bengal to assess the prevalence of keratosis and pigmentation was carried on 4,093 females and 3,590males who were exposed to arsenic toxicity. The result revealed that men took the same exposure of arsenic through drinking water had two to three times more toxicity on both keratosis and pigmentation than the females. Chronic arsenic toxicity also produces various systemic manifestations over and above skin lesions in association with arsenical skin lesions.

Respiratory disease

Non-malignant lung diseases are caused due to long exposure of arsenic contaminated drinking water(800 mg/L).About 38% of the arsenic exposed persons were experienced chronic cough, compared with3.1% of the unexposed one. Chronic lung diseases were common in 57% of the exposure of chronic arsenic toxicity through arsenic contaminated drinking water in West Bengal. [19,20]

Gastrointestinal disease

Dyspepsia one of the most dominated (38.4%) gastrointestinal syndrome for chronic arsenic toxicity.[19] Gastroenteritis also caused by chronic arsenic sis through the drinking of arsenic-contaminated water with a concentration greater than 50 mg/L.

Diseases of nervous system

Peripheral neuropathy is caused by chronic exposure of arsenic through drinking water. Peripheral neuritis characterized by paresthesia (tingling, numbness, limb weakness, and others) was present in 47.4% of total patients of chronic arsenic sis in West Bengal, India. Several reports revealed that increased incidence of cerebrovascular disease in patients suffering from chronic arsenic sis. There are also other neural complications such as peripheral neuritis, sleep disturbances, weakness, and cognitive and memory impairment also reported.

Cardiovascular disease

The important complications of chronic arsenic toxicity is Blackfoot disease (BFD), a peripheral vascular disease. The prevalence of BFD has been reported as 8.9% of the affected people in arsenic. Another peripheral vascular disorder such as Raynaud's syndrome and acrocyanosis with varying degrees of severity have also been reported in West Bengal. Apart from that arsenic toxicity also increases around 6.2% of the prevalence of hypertension in West Bengal.

Haematological effects

Acute and chronic arsenic poisoning leads to anemia, leucopenia, and thrombocytopenia and other haematological abnormalities. West Bengal carries average 50% anemia were caused in the exposure to arsenic-contaminated groundwater (200-2,000 mg/L).

Diabetes

Cumulative arsenic exposure and prevalence of diabetes mellitus were showed dose response relationship in arsenic endemic areas. In Bangladesh, diabetes mellitus prevalence also increased significantly where arsenic-contaminated water was taken as drinking water. There is no such report of diabetes mellitus caused by arsenic sis in West Bengal. [21,22]

Arsenicosis and cancer

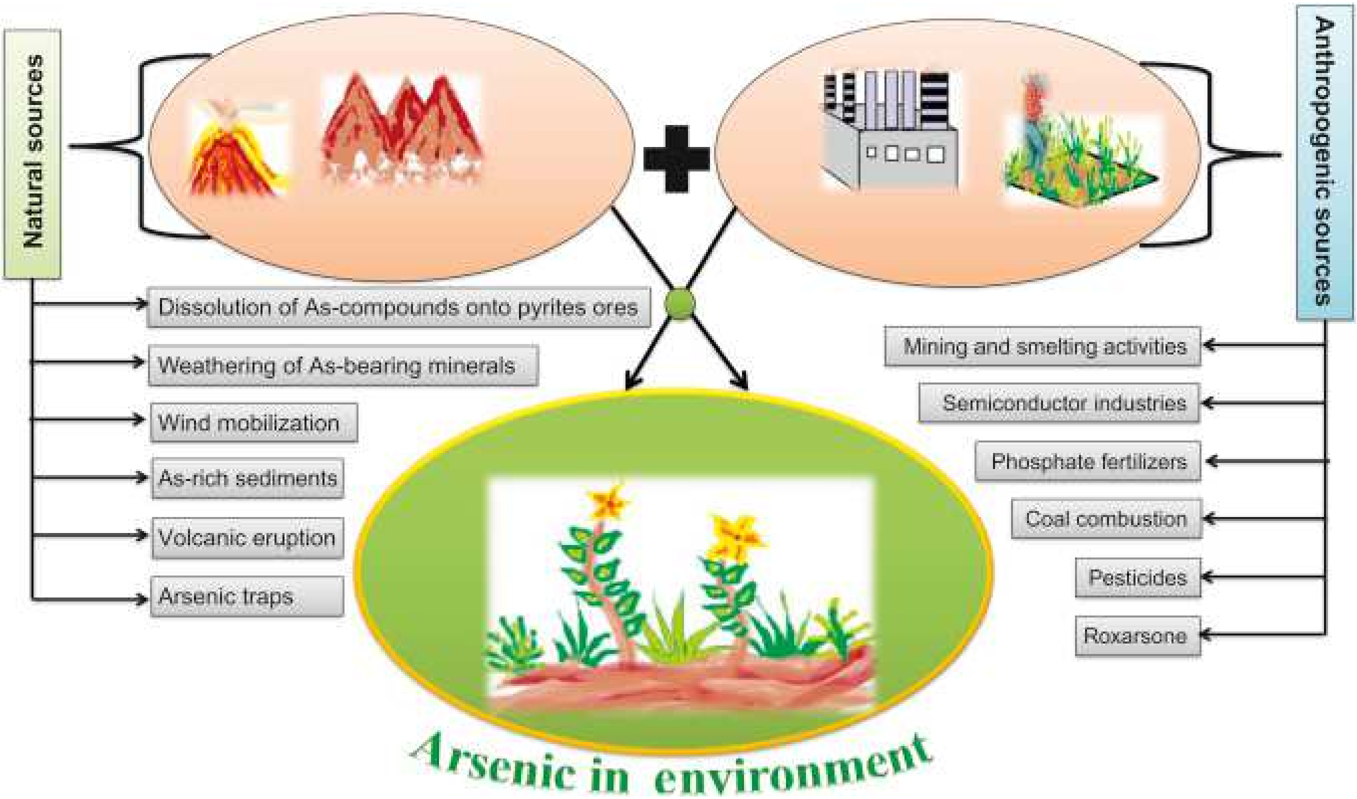
Exposure to arsenic leads severe carcinogenicity in humans through drinking water. This carcinogenicity is principally responsible in skin, urinary bladder, and lungs, among them 4.35% of skin cancer and 0.78% of internal cancers were detected in arsenic-affected villages In West Bengal through arsenic contamination.

Genotoxic effects

A long-term exposure of arsenic through drinking water expresses genotoxic effects which includes increased rate of chromosomal aberrations and micronuclei formation in buccal and urothelial cells. In West Bengal, the frequencies of formation of micronuclei were significantly high in peripheral lymphocytes, oral mucosa and urothelial cells and this effect is near 5-fold higher to exposed persons than unexposed ones.

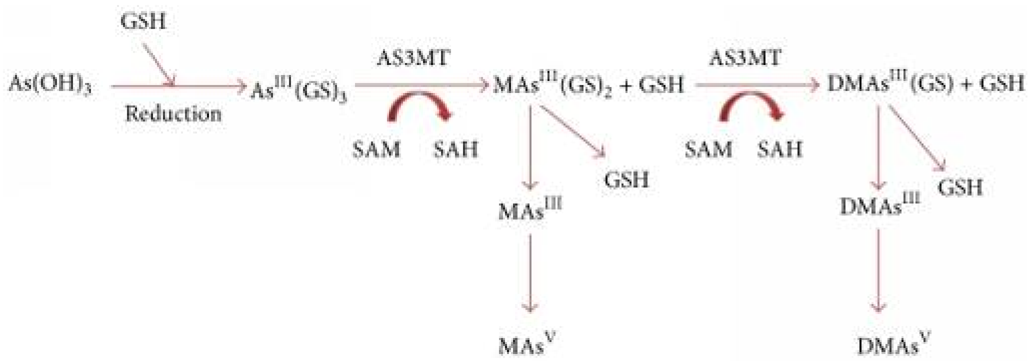
Results

Arsenic (As) is one of the oldest and important poison of global environment and becoming a serious threat to crop production.

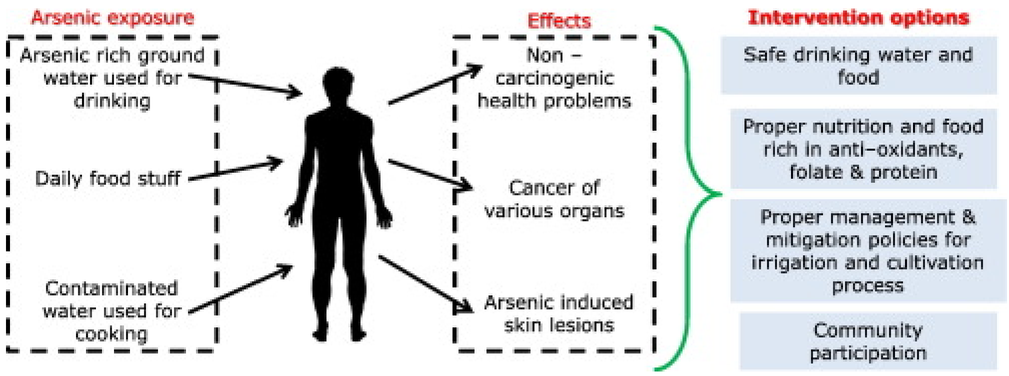


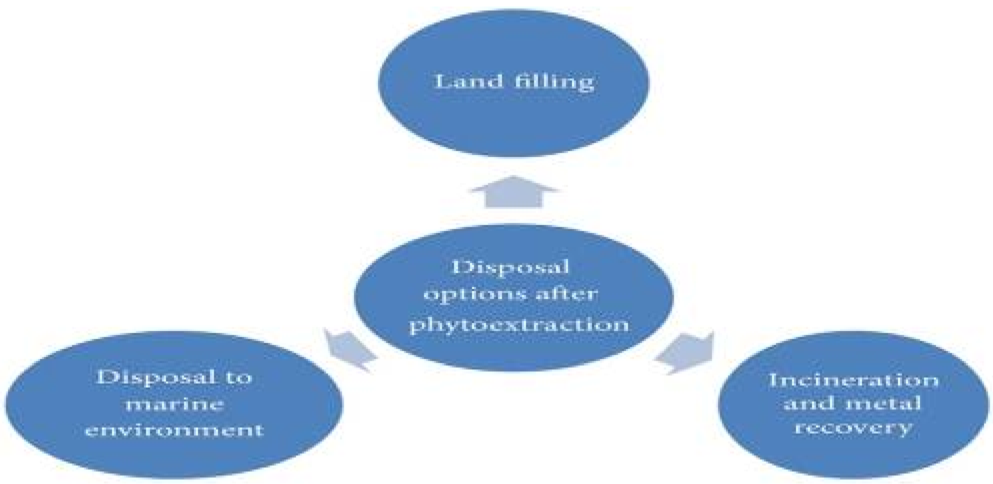
The As contamination in the environment is increasing day by day and both plant and animal faces its hazardous effect. As accumulated in the soil and ground water by anthropogenic and geogenic sources and enter into the food chain. Presence of As in water and food chain causes severe chronic diseases to human health. Higher concentration of As interferes plant metabolism which causes growth reduction, yield and, even plant death. In plants, As disrupts the biochemical function of cells which severely hampers photosynthesis, transpiration, respiration, plant metabolism and other physiological activities and finally arrests plant growth. Plant exposure to As generates reactive oxygen species (ROS) which imposes oxidative stress on plant leading to damage of protein, amino acid, nucleotide and nucleic acid. Considering the harmful effects of As it is necessary to find out suitable mechanisms to cope with As problem. Water management, nutrient management, genetic improvement, antioxidant defense, synthesis of metabolites, etc. are the possible ways in mitigating As toxicity. Several phytoremediation technologies like phytoextraction, phytostabilization, phytodegradation, rhizofiltration, etc. are plant-based remediation technology has recently come into attention to cleanup As contaminated soil and water.[23,24] Phytoextraction is the most important phytoremediation process helps to recover metal from the soil using non-food crop. Genetic and physiological potential of some plant species making them effective to accumulate, translocate and tolerate high concentration of metals and are used for phytoremediation. Few hyper accumulating species, especially ferns (e.g. Pteris vitta) and some higher classes of terrestrial, aquatic plant species and Mediterranean aquatic plant have been performing their potential towards As removal and remediation of soils and water. Phytochelatin (PC) formation within the plants' cell is one of basic thing and very important for the accumulation of As within the cell. Development of plant species through transgenic or biotechnological approaches capable to accumulate and tolerate high quantity of As might be good tools for reducing As toxicity.

Numerous terms are being used simultaneously in the literature to refer to these processes and may overlap to some extent. [25]



Phytoremediation consists of four to five different technologies each having a different mechanism such as the following.(1)Phytoextraction or phytomining or phytoaccumulation: plants take up and translocate metal contaminants from soil to the above ground portions, which then are harvested to remove the contaminant from the site.(2)Phytodegradation or phytotransformation: plants disintegrate pollutants which may occur within the plant by the metabolic activity or breakdown of the pollutant external to the plant contributed by various organic compounds released into the rhizosphere.(3)Rhizofiltration: plants get rid of contaminants present in solution surrounding the root zone by adsorption or precipitation onto their roots or absorption of contaminants into their roots from the solution. This technique is used to clean contaminated water such as groundwater or a waste stream.(4)Phytostabilization: plants immobilize contaminants in the soil and groundwater through absorption and accumulation by root or precipitation within the rhizosphere.(5)Phytovolatilization: plants volatilize pollutants; they take up the pollutants from the soil or water in the transpiration stream and volatilize into the atmosphere in a modified or unmodified form.Arsenic phytoremediation involves immobilization, fixation, and removal either as fixed in soil or accumulated in plant parts.[26]





Conclusions

Arsenic toxicity in soil and water is an increasing menace across the world and it is causing significant health damage to people living in developing and third world countries. It can be declared as a global hazard. Such a situation demands low-cost, technologically simple and point of use solutions to arsenic toxicity.[27]

Phytoremediation is a sustainable option for developing countries which are hit by economic crisis and thus cannot afford technologically sophisticated solutions for their huge populations. Many plant species especially aquatic macrophytes and some wetland plants have shown promising ability to uptake arsenic from contaminated environments. Free metal ions in the soil solution are absorbed by plants and are reduced as metal chelates using specific high-affinity ligands (like oxygen-donor ligands, sulfur-donor ligands, and nitrogen-donor ligands). Bioaccumulation in stems and leaves along phytovolatilization have been shown to be possible tolerance mechanisms by plants against arsenic contamination.[28]

References

[1] M. Pantsar-Kallio and A. Korpela, "Analysis of gaseous arsenic species and stability studies of arsine and trimethylarsine by gas chromatography-mass spectrometry," *Analytica Chimica Acta*, vol. 410, no. 1-2, pp. 65–70, 2000.View at: Publisher Site | Google Scholar

[2] C. F. Balasoiu, G. J. Zagury, and L. Deschênes, "Partitioning and speciation of chromium, copper, and arsenic in CCA-contaminated soils: influence of soil composition," *Science of the Total Environment*, vol. 280, no. 1–3, pp. 239–255, 2001.View at: Publisher Site | Google Scholar

[3] B. Rathinasabapathi and L. Q. Ma, "Arsenic hyper accumulating ferns and their application to phytoremediation of arsenic contaminated sites," in *Floriculture, Ornamental and Plant Biotechnology: Advances and Topical Issues*, pp. 304–311, Global Science Books, London, UK, 1st edition, 2006.View at: Google Scholar

[4] Z. Feng, Y. Xia, D. Tian et al., "DNA damage in buccal epithelial cells from individuals chronically exposed to arsenic via drinking water in Inner Mongolia, China," *Anticancer Research*, vol. 21, no. 1, pp. 51–57, 2001.View at: Google Scholar

[5] R. D. Tripathi, S. Srivastava, S. Mishra et al., "Arsenic hazards: strategies for tolerance and remediation by plants," *Trends in Biotechnology*, vol. 25, no. 4, pp. 158–165, 2007.View at: Publisher Site | Google Scholar

[6] R. Zhao, M. Zhao, H. Wang, Y. Taneike, and X. Zhang, "Arsenic speciation in moso bamboo shoot—a terrestrial plant that contains organoarsenic species," *Science of the Total Environment*, vol. 371, no. 1–3, pp. 293–303, 2006.View at: Publisher Site | Google Scholar

[7] SOS Arsenic Poisoning in Bangladesh/India, 2011, http://www.sos-arsenic.net.

[8] C.-J. Chen, C. W. Chen, M.-M. Wu, and T.-L. Kuo, "Cancer potential in liver, lung, bladder and kidney due to ingested inorganic arsenic in drinking water," *British Journal of Cancer*, vol. 66, no. 5, pp. 888–892, 1992.View at: Google Scholar

[9] S. Kapaj, H. Peterson, K. Liber, and P. Bhattacharya, "Human health effects from chronic arsenic poisoning—a review," *Journal of Environmental Science and Health A*, vol. 41, no. 10, pp. 2399–2428, 2006.View at: Publisher Site | Google Scholar

[10] Committee on Medical, Biological Effects of Environmental Pollutants, and National Research Council, *Arsenic: Medical and Biological Effects of Environmental Pollutants*, National Academy of Sciences, Washington, DC, USA, 1977.

[11] R. T. Nickson, J. M. McArthur, B. Shrestha, T. O. Kyaw-Myint, and D. Lowry, "Arsenic and other drinking water quality issues, Muzaffargarh District, Pakistan," *Applied Geochemistry*, vol. 20, no. 1, pp. 55–68, 2005.View at: Publisher Site | Google Scholar

[12] P. C. Nagajyoti, K. D. Lee, and T. V. M. Sreekanth, "Heavy metals, occurrence and toxicity for plants: a review," *Environmental Chemistry Letters*, vol. 8, no. 3, pp. 199–216, 2010.View at: Publisher Site | Google Scholar

[13] National Research Council (NRC), Current Issues and Studies, 1977, www.eric.ed.gov/ERICWebPortal.

[14] B. K. Mandal and K. T. Suzuki, "Arsenic round the world: a review," *Talanta*, vol. 58, no. 1, pp. 201–235, 2002.View at: Publisher Site | Google Scholar

[15] W. J. Fitz and W. W. Wenzel, "Arsenic transformations in the soil-rhizosphere-plant system: fundamentals and potential application to phytoremediation," *Journal of*

Biotechnology, vol. 99, no. 3, pp. 259–278, 2002.View at: Publisher Site | Google Scholar

[16] B. K. Chopra, S. Bhat, I. P. Mikheenko et al., "The characteristics of rhizosphere microbes associated with plants in arsenic-contaminated soils from cattle dip sites," *Science of the Total Environment*, vol. 378, no. 3, pp. 331–342, 2007.View at: Publisher Site | Google Scholar

[17] X. Sun and H. E. Doner, "An investigation of arsenate and arsenite bonding structures on goethite by FTIR," *Soil Science*, vol. 161, no. 12, pp. 865–872, 1996.View at: Google Scholar

[18] R. R. Frost and R. A. Griffin, "Effect of pH on adsorption of as and selenium from landfill leachate by clay minerals," *Soil Science Society of America Journal*, vol. 41, no. 1, pp. 53–57, 1977.View at: Publisher Site | Google Scholar

[19] S. H. Mueller, R. J. Goldfarb, G. L. Farmer, R. Sanzolone, M. Adams, and P. Theodorakus, "A seasonal study of arsenic and groundwater geochemistry in Fairbanks, Alaska," in *Proceedings of the USGS Workshop on Arsenic in the Environment*, Denver, Colorado, February 2001.View at: Google Scholar

[20] N. P. Nikolaidis, G. M. Dobbs, J. Chen, and J. A. Lackovic, "Arsenic mobility in contaminated lake sediments," *Environmental Pollution*, vol. 129, no. 3, pp. 479–487, 2004.View at: Publisher Site | Google Scholar

[21] P. L. Smedley, H. B. Nicolli, D. M. J. Macdonald, A. J. Barros, and J. O. Tullio, "Hydrogeochemistry of arsenic and other inorganic constituents in ground waters from La Pampa, Argentina," *Applied Geochemistry*, vol. 17, no. 3, pp. 259–284, 2002.View at: Publisher Site | Google Scholar

[22] D. C. Adriano, *Trace Elements in Terrestrial Environments: Bio Geochemistry, Bioavailability, and Risk of Metals*, Springer, New York, NY, USA, 2nd edition, 2001.

[23] J. C. Ng, J. Wang, and A. Shraim, "A global health problem caused by arsenic from natural sources," *Chemosphere*, vol. 52, no. 9, pp. 1353–1359, 2003.View at: Publisher Site | Google Scholar

[24] E. K. Porter and P. J. Peterson, "Arsenic accumulation by plants on mine waste (United Kingdom)," *Science of the Total Environment*, vol. 4, no. 4, pp. 365–371, 1975.View at: Publisher Site | Google Scholar

[25] T. de Koe, *Arsenic resistance in submeditemanean Agrotis species, [Ph.D. thesis]*, Vrije Universiteit, Amsterdam, The Netherlands, 1994.

[26] A. M. Benavides, *The effect of arsenic speciation on arsenic uptake and fate in the presence of the hyper-accumulating species Pteris cretica, [Master of Science]*, 2007.

[27] S. Mahimairaja, N. S. Bolan, D. C. Adriano, and B. Robinson, "Arsenic contamination and its risk management in complex environmental settings," *Advances in Agronomy*, vol. 86, pp. 1–81, 2005.View at: Publisher Site | Google Scholar

[28] X. Y. Zhang, F. F. Lin, M. T. F. Wong, X. L. Feng, and K. Wang, "Identification of soil heavy metal sources from anthropogenic activities and pollution assessment of Fuyang County, China," *Environmental Monitoring and Assessment*, vol. 154, no. 1–4, pp. 439–449, 2009.View at: Publisher Site | Google Scholar